

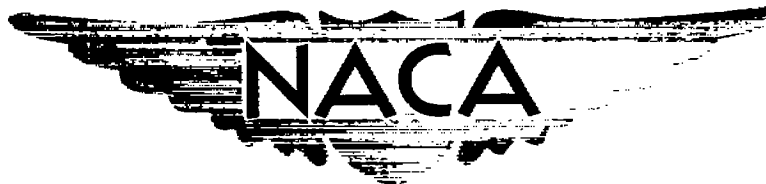
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# RESEARCH MEMORANDUM

ADDITIONAL MEASUREMENTS OF THE LOW-SPEED STATIC  
STABILITY OF A CONFIGURATION EMPLOYING  
THREE TRIANGULAR WING PANELS  
AND A BODY OF EQUAL LENGTH

By Noel K. Delany

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## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

July 25, 1955

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## AND A BODY OF EQUAL LENGTH

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## SUMMARY

An experimental investigation has been conducted at low speeds of the static-stability characteristics of a simplified model of an unusual configuration. The model had three triangular airfoils of low aspect ratio. One of the airfoils was mounted vertically on top of a body of revolution as a fin, and the other two were mounted as the main lifting surfaces. The leading edges of the airfoils used as the main lifting surfaces were swept back  $73.9^\circ$ . Two vertical fins were investigated; one was the same as the main lifting surfaces, the other had the leading edge swept back  $76.0^\circ$ . The body had the same length as the airfoils.

Results of tests of the simplified model of the configuration are presented for a large range of angles of attack and sideslip for several dihedral angles. Some data were also obtained on the damping-in-roll characteristics of the model at  $0^\circ$  angles of attack and sideslip.

## INTRODUCTION

An airplane configuration having three identical triangular airfoils of low aspect ratio radiating symmetrically from a central body that does not protrude ahead of the wings has been suggested as a promising arrangement for flight at very high speeds. The results of an investigation of the low-speed static stability of a simplified model of such an arrangement having one of the airfoils placed vertically on top of the body and the other two as wing panels having negative dihedral are presented in reference 1.

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In order to provide information for predicting the effects of changes in the basic configuration on the low-speed stability characteristics presented in reference 1, additional measurements have been made. The effects of changes in dihedral and in the size of the vertical fin were investigated for a large range of angles of attack and sideslip. The contributions of the various components of the model to the static stability and to the damping in roll were also considered.

The investigation was conducted in a 7- by 10-foot wind tunnel at the Ames Aeronautical Laboratory at a Mach number of approximately 0.25 which corresponded to a Reynolds number of about 4.5 million based on the mean aerodynamic chord.

#### NOTATION

A diagram showing the system of axes and the positive directions of forces and moments used in presenting the data is shown in figure 1. The axes of all forces and moments pass through the moment center of the model. The moment center was 0.37 of the mean aerodynamic chord behind the leading edge of the mean aerodynamic chord. Both the body axes and the stability system of axes are defined in figure 1; however, unless otherwise specified all results are presented with respect to the body axes. The symbols used in the report are defined as follows:

b	wing span (twice the panel span), ft
$\bar{c}$	mean aerodynamic chord of the wing, $\frac{\int_0^{b/2} c^2 dy}{\int_0^{b/2} c dy}$ , ft
c	wing chord parallel to plane of symmetry, ft
$C_A$	axial-force coefficient, $\frac{F_A}{qS}$
$C_{D_S}$	drag coefficient referred to stability axes, $\frac{F_{D_S}}{qSb}$
$C_L$	lift coefficient, $\frac{F_L}{qS}$
$C_l$	rolling-moment coefficient referred to body axes, $\frac{M_X}{qSb}$
$C_{l_p}$	rate of change of rolling-moment coefficient with rolling- angular-velocity factor $\frac{\partial C_{l_S}}{\partial (pb/2V_0)}$
$C_{l_S}$	rolling-moment coefficient referred to stability axes, $\frac{M_{X_S}}{qSb}$

$C_m$	pitching-moment coefficient, $\frac{M_y}{qS\bar{c}}$
$C_N$	normal-force coefficient, $\frac{F_N}{qS}$
$C_n$	yawing-moment coefficient referred to body axes, $\frac{M_Z}{qSb}$
$C_{n_s}$	yawing-moment coefficient referred to stability axes, $\frac{M_{Z_s}}{qSb}$
$C_Y$	side-force coefficient, $\frac{F_Y}{qS}$
$F_A$	axial force, positive along $-X$ axis, lb
$F_{D_s}$	drag force, positive along $-X_s$ axis, lb
$F_L$	lift force, positive along $-Z_s$ axis, lb
$F_N$	normal force, positive along $-Z$ axis, lb
$F_Y$	side force, positive along the $Y$ or $Y_s$ axis, lb
$\frac{L}{D}$	ratio of lift to drag $\frac{C_L}{C_{D_s}}$
$M_X$	rolling moment about the $X$ axis, positive clockwise looking forward, ft-lb
$M_{X_s}$	rolling moment about the $X_s$ axis, positive clockwise looking forward, ft-lb
$M_Y$	pitching moment about the $Y$ or $Y_s$ axis, positive moment raises the nose, ft-lb
$M_Z$	yawing moment about $Z$ axis, positive moment rotates nose to right, ft-lb
$M_{Z_s}$	yawing moment about $Z_s$ axis, positive moment rotates nose to right, ft-lb
$p$	rolling angular velocity, radians per/sec
$\frac{pb}{2V_o}$	rolling-angular-velocity factor of helix generated by wing tip in roll, radians
$q$	dynamic pressure, lb/sq ft
$S$	wing area (twice panel area), sq ft
$V_o$	free-stream velocity, ft/sec

$\alpha$	angle of attack, deg
$\beta$	angle of sideslip, deg
$\Gamma$	dihedral angle, deg
$\delta_a$	total aileron deflection, positive deflection gives a positive rolling moment, deg
$\delta_r$	rudder deflection, positive, trailing edge to left, deg
$X$	longitudinal body axis, in vertical plane of symmetry and coincident with center line of body, positive forward
$X_S$	longitudinal stability axis, parallel to the projection of the relative wind on the vertical plane of symmetry, positive forward
$Y$	lateral body axis, perpendicular to vertical plane of symmetry, positive to right when looking forward
$Y_S$	lateral-stability axis, perpendicular to vertical plane of symmetry, positive to right when looking forward
$Z$	vertical body axis, in vertical plane of symmetry and perpendicular to the longitudinal and lateral body axes, positive downward
$Z_S$	vertical stability axis, in vertical plane of symmetry and perpendicular to the relative wind, positive downward

#### MODEL AND APPARATUS

The model and apparatus were the same as those used in the investigation reported in reference 1. The basic model consisted of three identical triangular airfoils radiating symmetrically from a body of revolution as shown in figure 2. The wing surfaces were 3/4-inch Douglas fir plywood with blunt trailing edges and with sharpened leading edges of solid mahogany. The wood was finished with a surface sealer, but a high degree of smoothness was not attempted. The panels were attached to the body with sheet-metal brackets inlaid flush into the airfoils but external to the surface of the body so as to facilitate changing the angular relation of the airfoils. It was possible to set the wing at dihedral angles of  $0^\circ$ ,  $-15^\circ$ , and  $-30^\circ$ .

Two different size airfoils were tested as the vertical surface. One had the same dimensions as the airfoils used for the wing, while the

other had the same root chord but a smaller span. The pertinent geometric characteristics of the airfoils are tabulated below:

Wing panels and large vertical fin

Aspect ratio . . . . .	0.58
Root chord, ft . . . . .	3.96
Span, body center line to tip, ft . . . . .	1.14
Area, sq ft . . . . .	2.26
Mean aerodynamic chord, ft . . . . .	2.64
Sweepback of leading edge, deg . . . . .	73.9

Small vertical fin

Aspect ratio . . . . .	0.50
Root chord, ft . . . . .	3.96
Span, body center line to tip, ft . . . . .	0.99
Mean aerodynamic chord, ft . . . . .	2.64
Sweepback of leading edge, deg . . . . .	76.0

A deflected rudder was simulated by a full-span (at the hinge line) split flap made of sheet metal and attached to the vertical fin with wedge-shaped brackets. The chord of the flap was 6 percent of the airfoil root chord.

The model was supported on a sting-mounted, four-component, strain-gage balance contained within the body. The diameter of the sting at the base of the body was 3.1 inches. A static-pressure orifice was installed in the annular space between the sting and the body to permit measurement of the average base pressure.

#### TESTS AND REDUCTION OF DATA

The sting support permitted angular movement of the model only about a vertical axis passing through the moment center; hence the angle of attack and angle of sideslip could not be varied independently. With one of the airfoils horizontal (considered the vertical fin), the angle of attack was varied at  $0^\circ$  sideslip, and with the same airfoil vertical, the angle of sideslip was varied at  $0^\circ$  angle of attack. Intermediate settings of the angle of bank produced attitudes of the model which combined finite angles of attack and sideslip. Data for specific angles of attack combined with sideslip were obtained by cross-plotting the basic wind-tunnel data for the model set to various intermediate angles of bank.

All forces and moments were measured relative to a system of orthogonal axes that were fixed with respect to the model (body axes). For a given attitude of the model in the wind tunnel, and with the four-component strain-gage balance properly aligned relative to the model,  $F_N$ ,  $F_A$ ,  $M_y$ , and  $M_x$  were measured. For the same attitude of the model in the wind tunnel but with the balance rotated  $90^\circ$  about its longitudinal axis from the above

position,  $F_Y$ ,  $F_A$ ,  $M_Z$ , and  $M_X$  were measured. Hence, for conditions where three force and three moment components were desired, it was necessary to obtain data for both positions of the balance relative to the model.

The steady-rolling technique was used to evaluate the damping in roll due to rolling for angles of attack and sideslip of  $0^\circ$ . For these tests the model was free to roll about the body axis. The split flaps were used as aerodynamic controls to drive the model in roll, and an electronic timer was used to measure the rate of roll. Since the rate of roll varied slightly due to flow fluctuations of the wind-tunnel stream, average values over a period of approximately 1 minute were used. The effect of friction on the rate of roll was negligible for the conditions presented.

The average pressure at the base of the model was measured, and the drag data have been corrected to correspond to a base pressure equal to free-stream static pressure. Because of the uncertainty of tunnel constriction effects and the exploratory nature of the investigation, no tunnel-wall corrections have been applied to the results.

## RESULTS AND DISCUSSION

The results presented in reference 1 mainly pertain to the configuration with a dihedral angle of  $-30^\circ$ . Measurements have been made with the same model as that of reference 1 to show the effects of the various components of the model on the static aerodynamic characteristics for several dihedral angles. Also included in the present report are some measurements of the static-stability characteristics with a smaller vertical tail, and of the damping in roll due to rolling.

The lift coefficient, pitching-moment coefficient, and lift-drag ratio of the body alone and of the wing-body combinations for dihedral angles of  $0^\circ$ ,  $-15^\circ$ , and  $-30^\circ$  are presented in figure 3 for a large range of angles of attack. It is noted that for a given angle of attack, less than about  $24^\circ$ , the lift coefficient varied with dihedral angle approximately as the square of the cosine of the dihedral angle.

The effects of the various components of the model (body alone, body plus large vertical fin, body plus wings, and complete model) on the variations with angle of sideslip of yawing-moment, rolling-moment, and side-force coefficients for an angle of attack of  $0^\circ$  are shown in figures 4(a), (b), and (c) for dihedral angles of  $0^\circ$ ,  $-15^\circ$ , and  $-30^\circ$ , respectively. In general, these variations of the lateral- and directional-stability coefficients with sideslip angle were approximately linear to  $20^\circ$  and did not have any sharp changes to  $32^\circ$ . Comparison of the data in figure 4 indicates that the mutual interference of the wing and the tail, for angles of sideslip of  $0^\circ$  to  $16^\circ$ , made  $C_{n\beta}$  and  $C_{l\beta}$  more positive and  $C_{y\beta}$  more

negative. The effect of the dihedral angle on the increment of  $C_{n\beta}$  and  $C_{l\beta}$  due to the interference was negligible; however, the increment of  $C_{Y\beta}$  due to the interference became more negative as the dihedral angle became more negative.

The effect of angle of attack on the forces and moments due to the split-flap control on the vertical fin (rudder) is shown in figure 5 for the model with  $-30^\circ$  of dihedral. For angles of attack between  $-8^\circ$  and  $32^\circ$  the values of  $C_{n\delta_r}$  and  $C_{l\delta_r}$  remained approximately constant at  $-0.0014$  and  $0.0004$ , per degree, respectively. For the same type and size of control on the wing, values of  $C_{n\delta_a}$  and  $C_{l\delta_a}$  of  $0.0007$  and  $0.0005$ , respectively (data not shown), were measured at  $0^\circ$  angle of attack ( $\delta_a$  is considered to be the total aileron deflection). From these values it can be noted that piloting procedure for a coordinated turn would differ from that for a conventional airplane because of the rather large adverse rolling moment due to rudder deflection and the favorable yawing moment due to aileron deflection.

The variation with angle of sideslip of yawing-moment, rolling-moment, side-force, normal-force, pitching-moment, and axial-force coefficients are presented in figures 6 and 7 for various angles of attack from  $0^\circ$  to  $40^\circ$ . The data in figure 6 are for the model with  $-15^\circ$  of dihedral and the large vertical fin; while the data in figure 7 are for the model with  $0^\circ$  of dihedral and the small vertical fin. The changes of these coefficients with angle of sideslip were relatively linear for angles of attack and sideslip up to about  $20^\circ$ . Figure 8 summarizes the effects of angle of attack on the static-stability parameters  $C_{n\beta}$  and  $C_{l\beta}$ . The variations of  $C_{n\beta}$  and  $C_{l\beta}$  were derived from the data in figure 6 of reference 1 and figures 6 and 7 of the present report for small angles of sideslip near zero. The variation with angle of attack of these parameters referred to the stability system of axes is also shown in figure 8. Interpolation between the data in figures 8(a) and (b) indicates that a model with a dihedral angle of approximately  $-25^\circ$  and the large vertical fin would have the minimum variation with angle of attack of  $C_{n\beta}$  and  $C_{l\beta}$  referred to the stability axes. The interpolation also indicates that  $C_{n\beta}$  and  $C_{l\beta}$  for this configuration would be approximately  $0.0015$  and  $-0.0003$ , respectively, between angles of attack of  $0^\circ$  and  $13^\circ$ .

The measured damping-in-roll parameter,  $C_{lp}$ , for  $0^\circ$  angle of attack and sideslip was  $0.126$  for two airfoils  $180^\circ$  apart ( $\Gamma = 0^\circ$ ), and was  $0.157$  for three airfoils  $120^\circ$  apart ( $\Gamma = -30^\circ$ ). Thus, three airfoils produced approximately 25 percent more damping than the two.

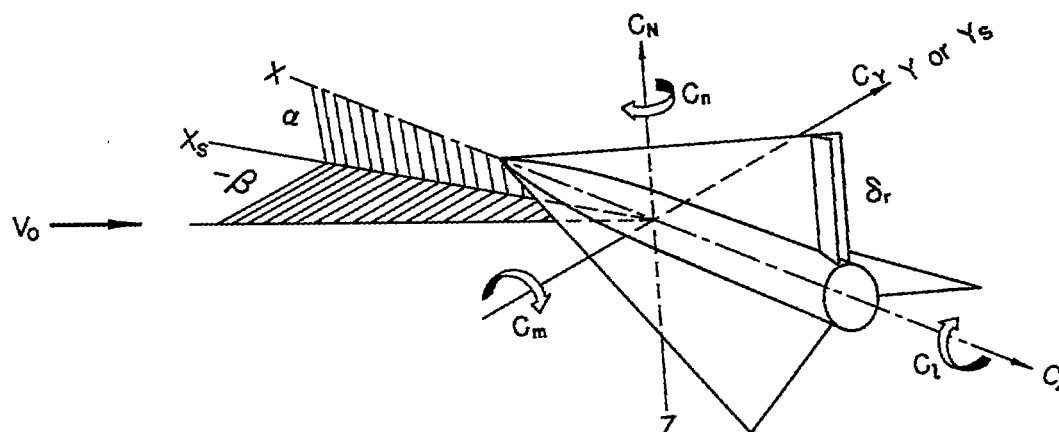


## REFERENCE

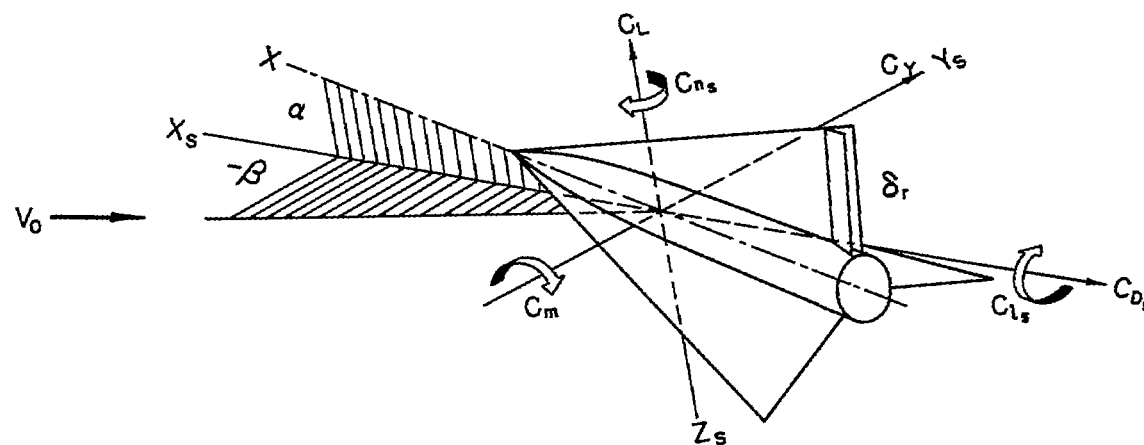
1. Delany, Noel K.: Exploratory Investigation of the Low-Speed Static Stability of a Configuration Employing Three Identical Triangular Wing Panels and a Body of Equal Length. NACA RM A55C28, 1955.

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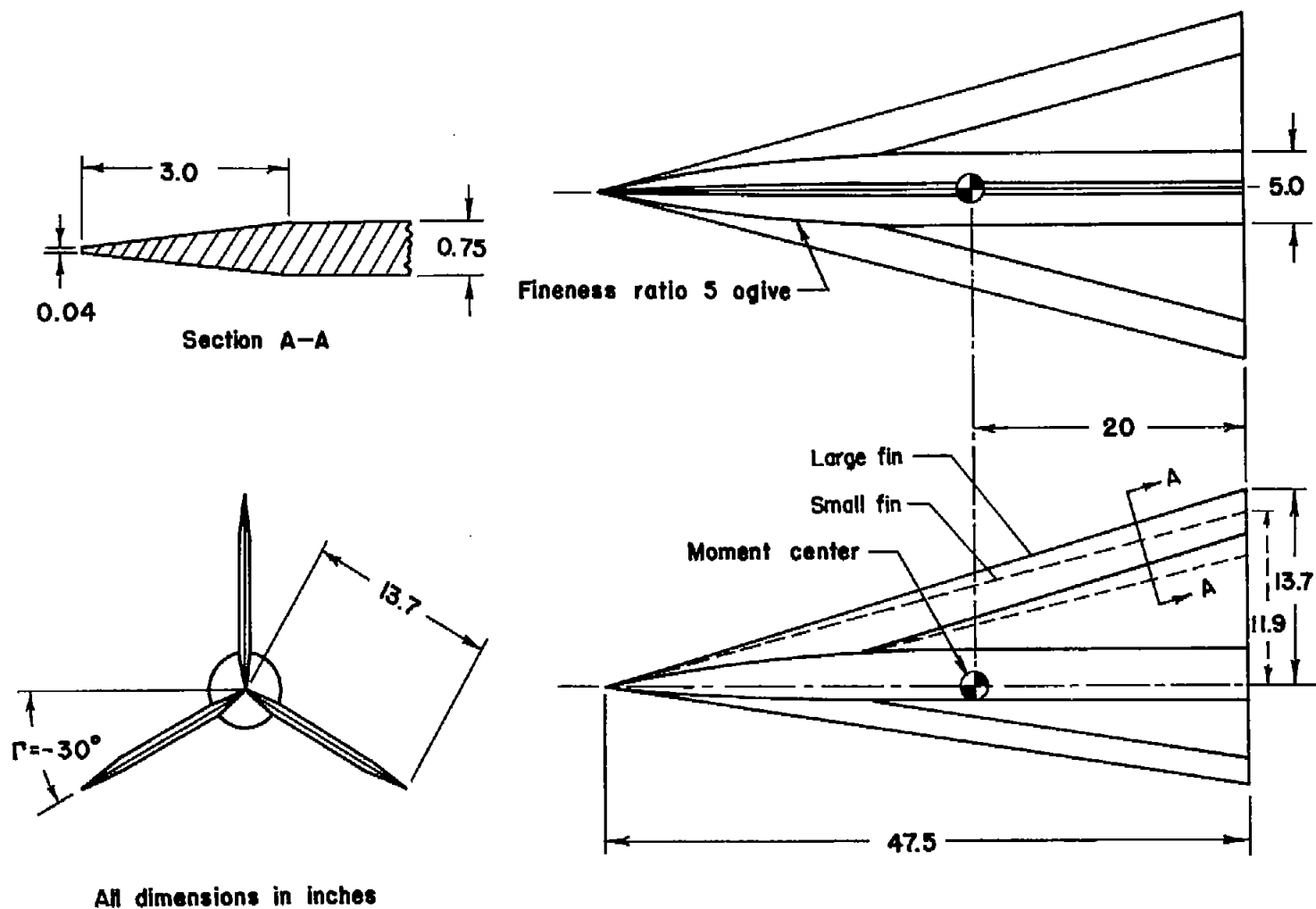


(a) Body axes.



(b) Stability axes.

Figure 1.- Systems of axes and sign convention.



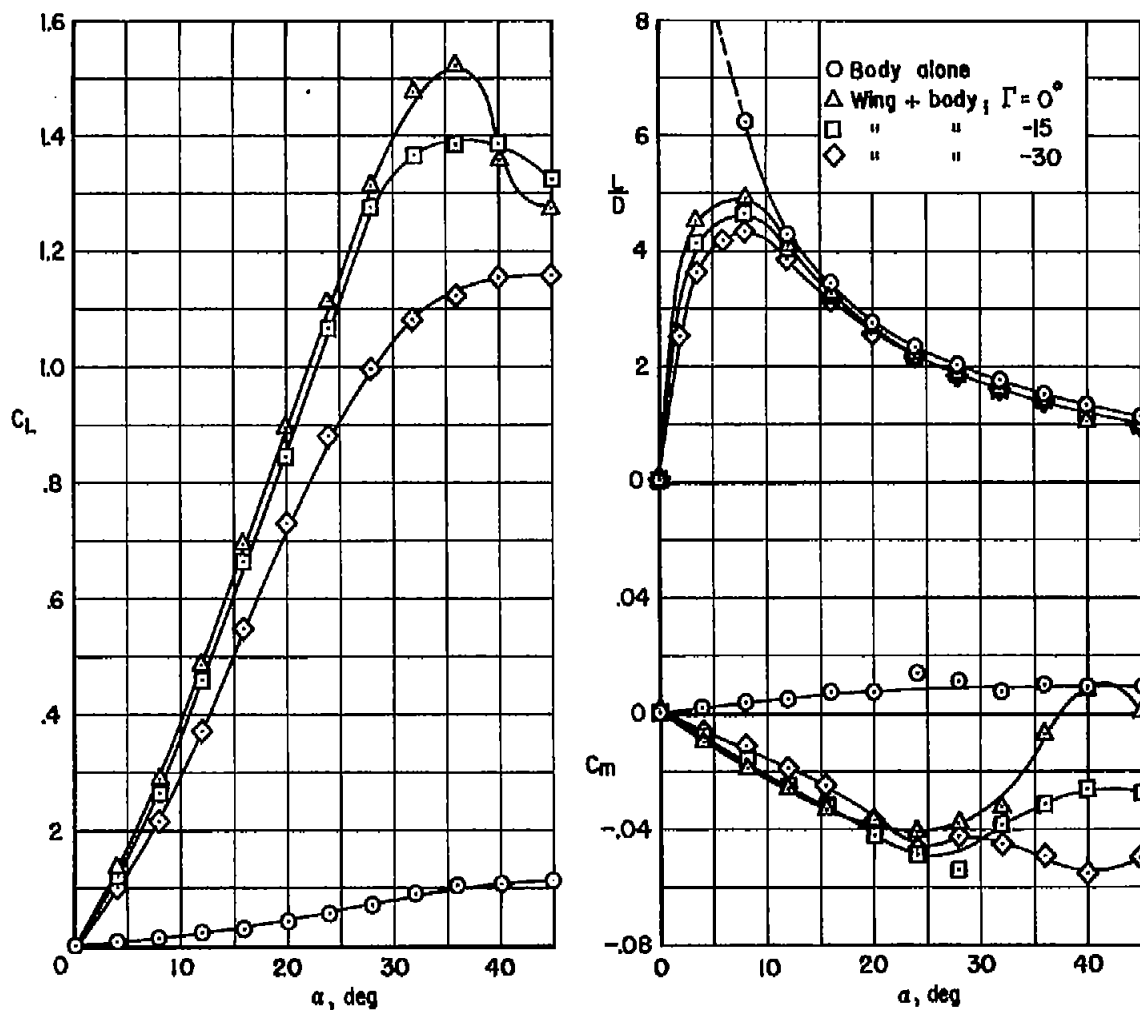
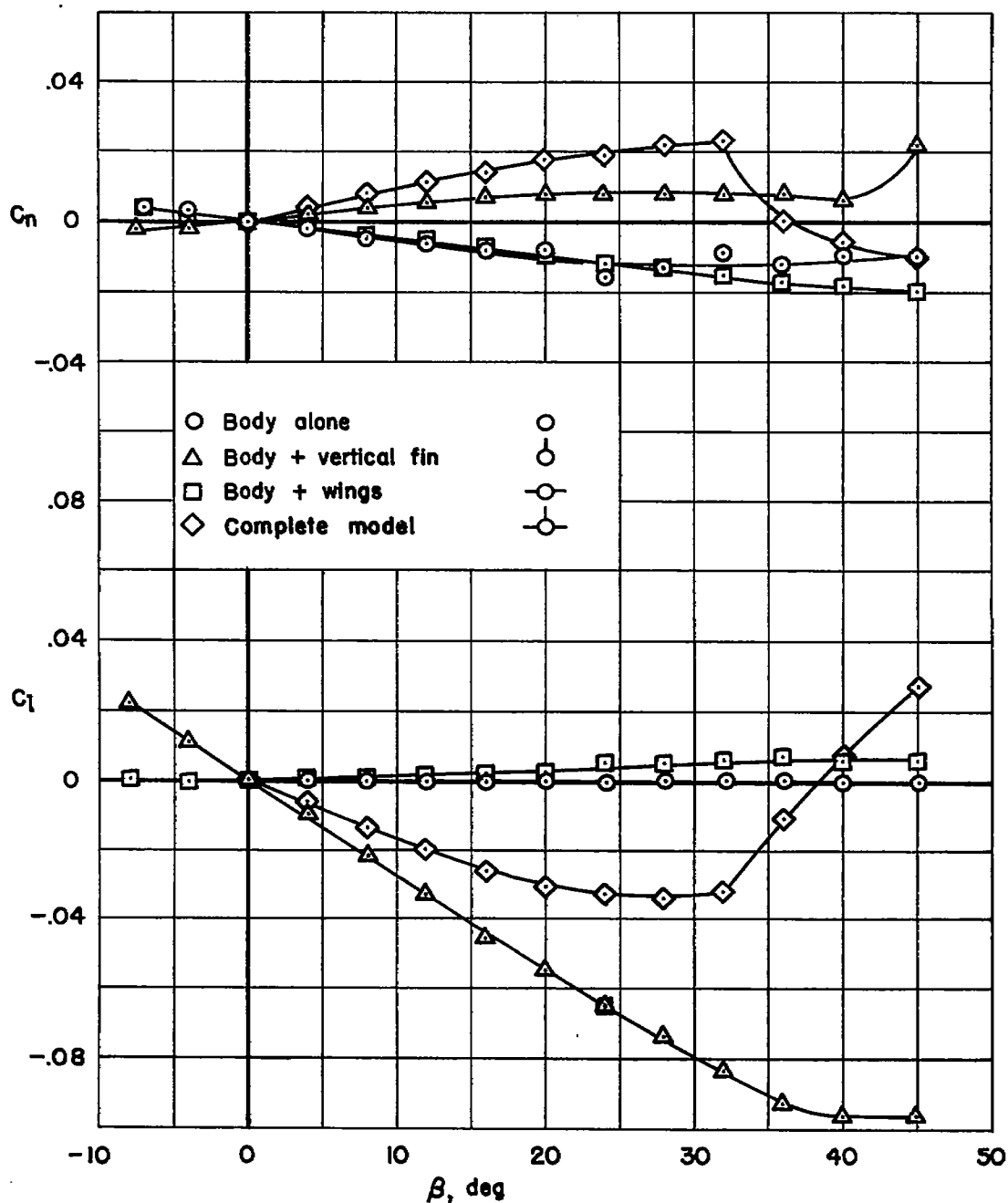
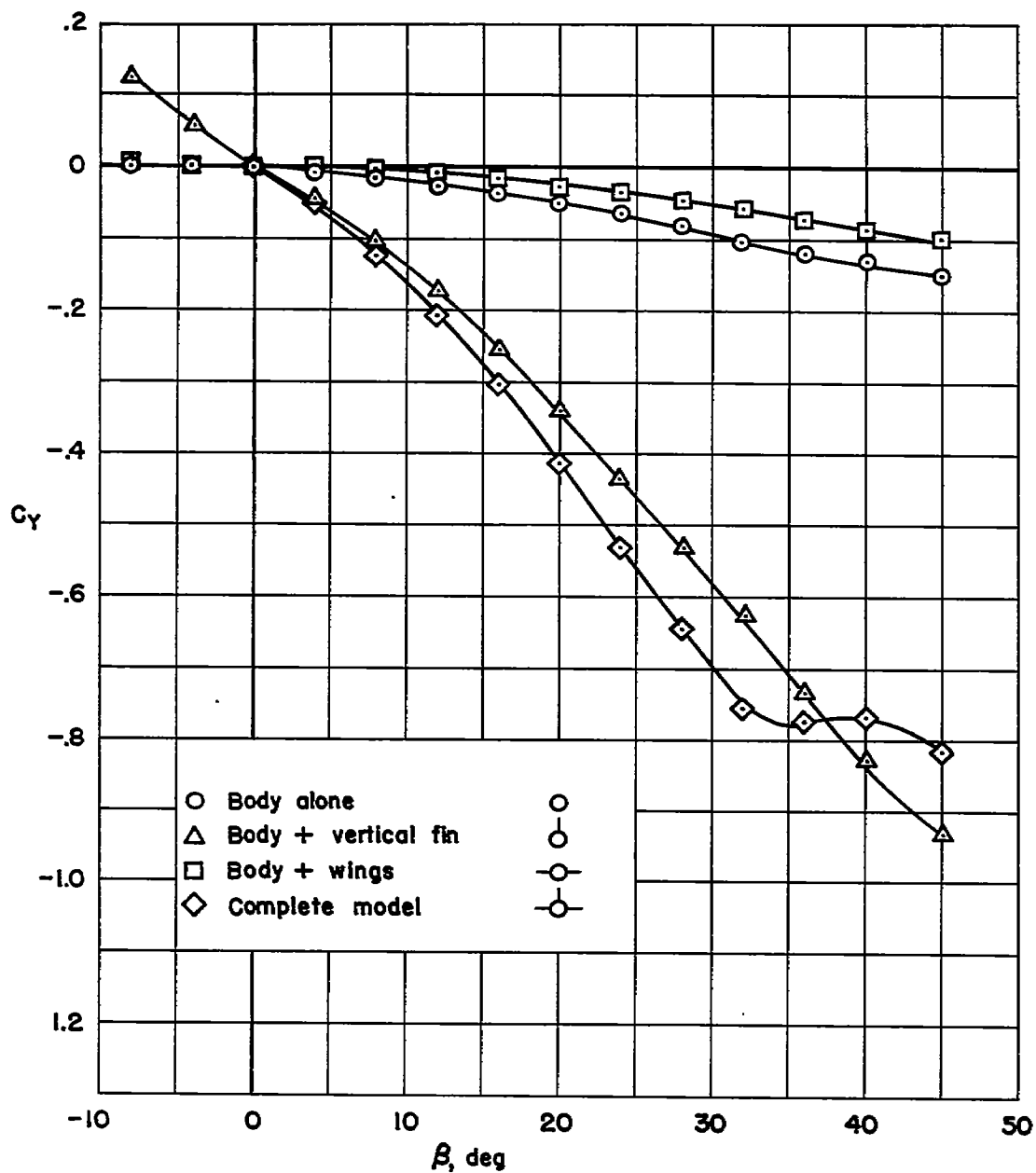


Figure 3.- Static longitudinal-stability characteristics for several dihedral angles; large vertical fin.



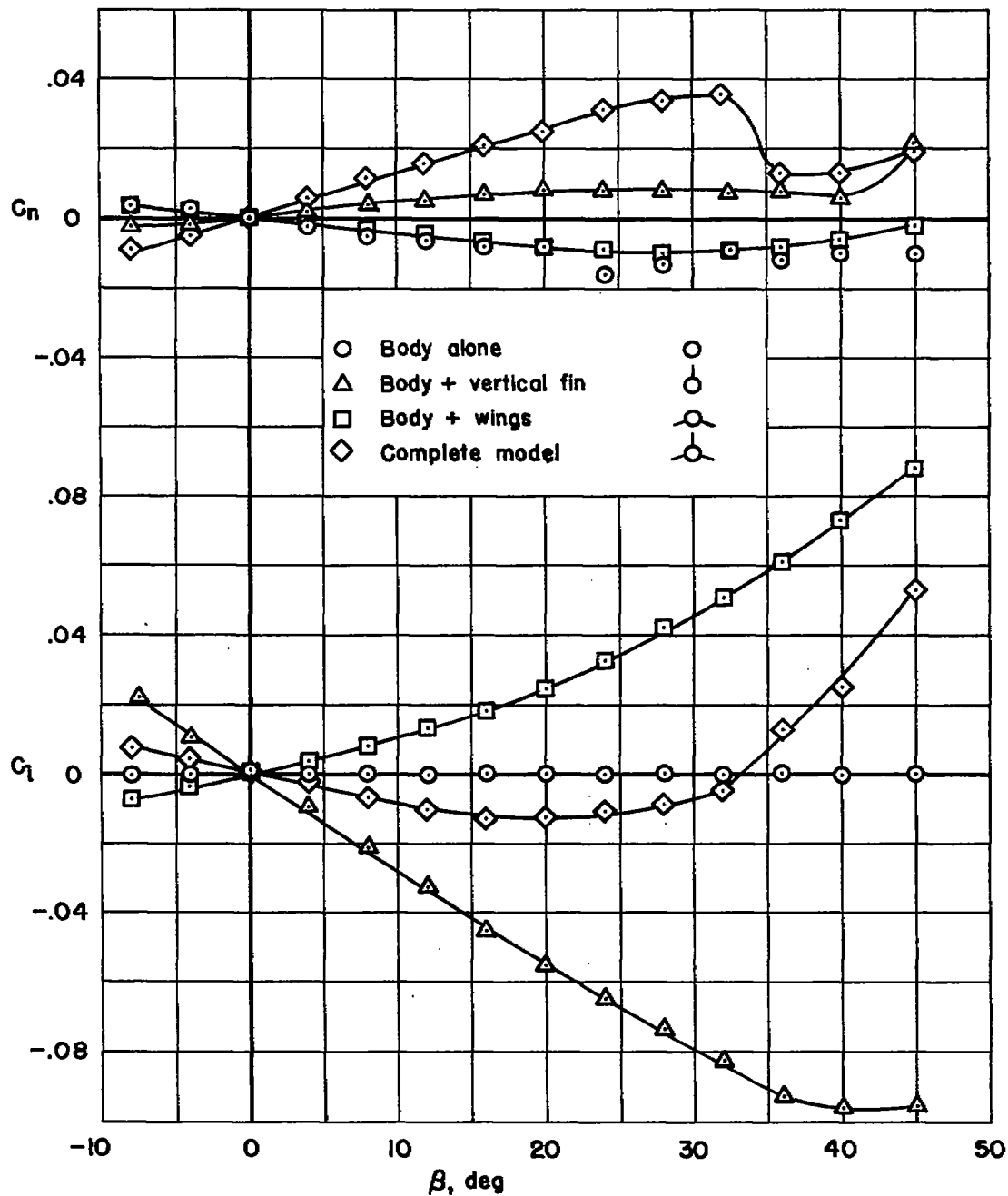
(a)  $\Gamma = 0^\circ$ .

Figure 4.- Effect of the component parts of the model on the static lateral and directional stability characteristics at  $\alpha = 0^\circ$ ; large vertical fin.



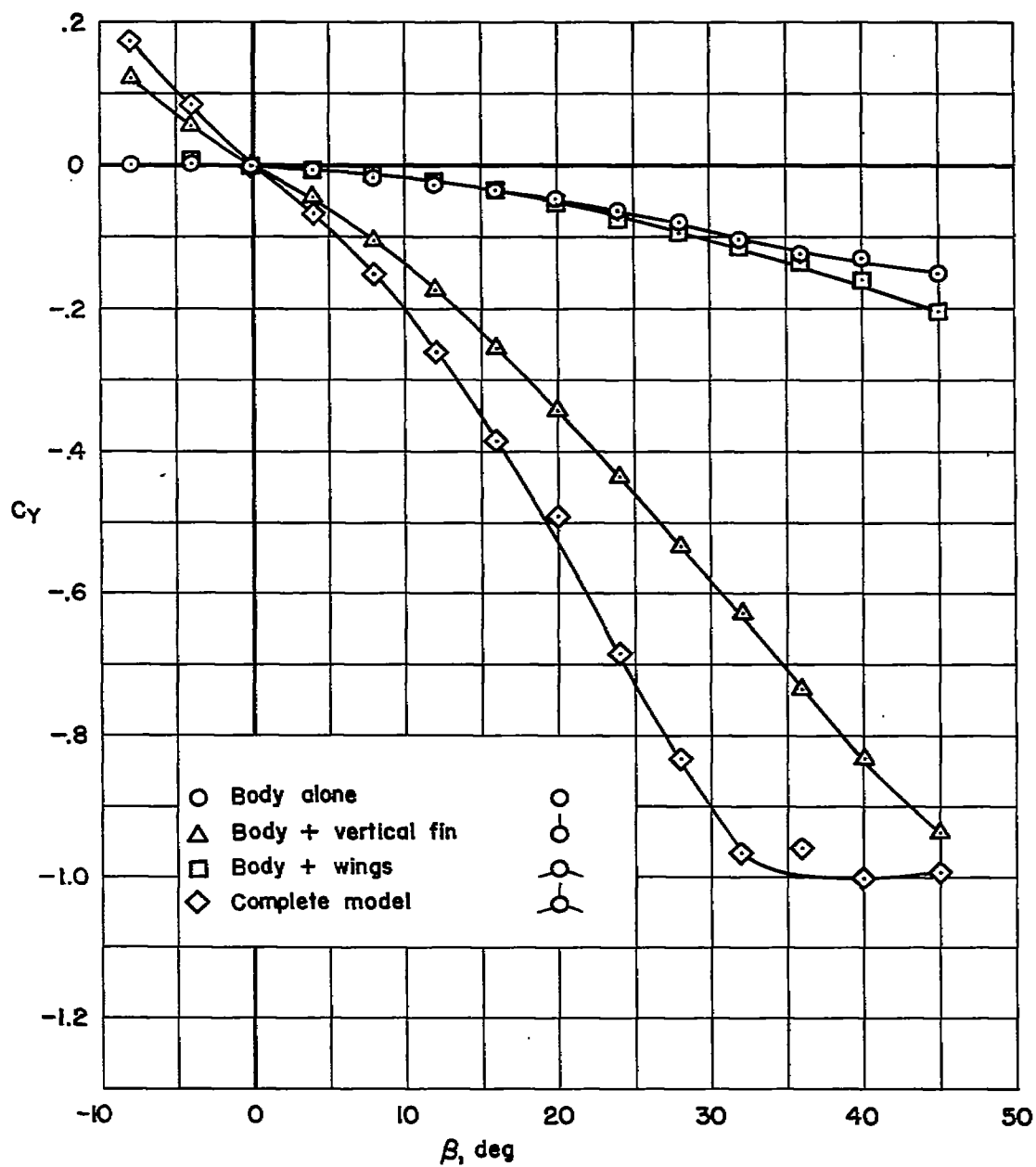
(a) Concluded.

Figure 4.- Continued.



(b)  $\Gamma = -15^\circ$ .

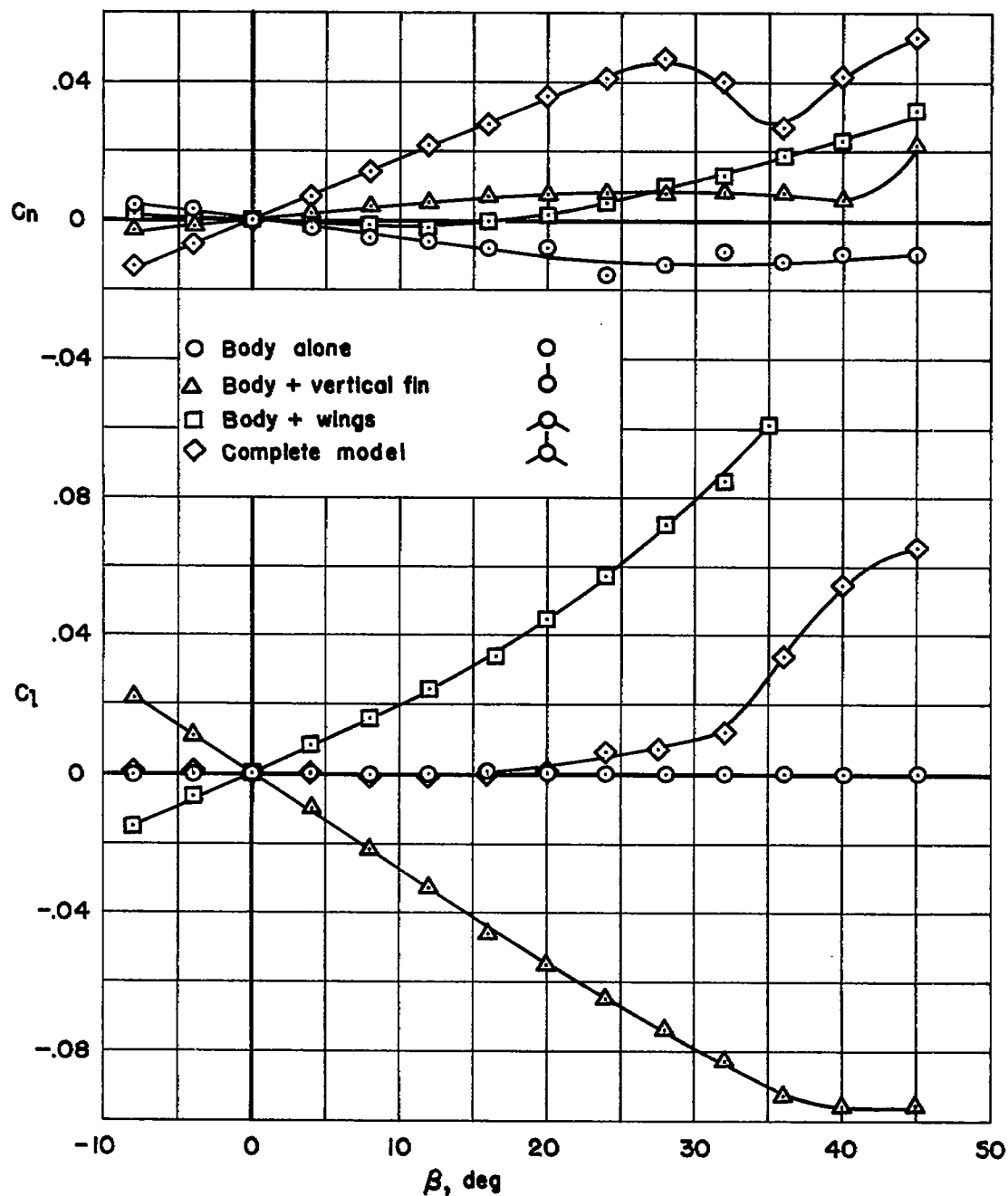
Figure 4.- Continued.



(b) Concluded.

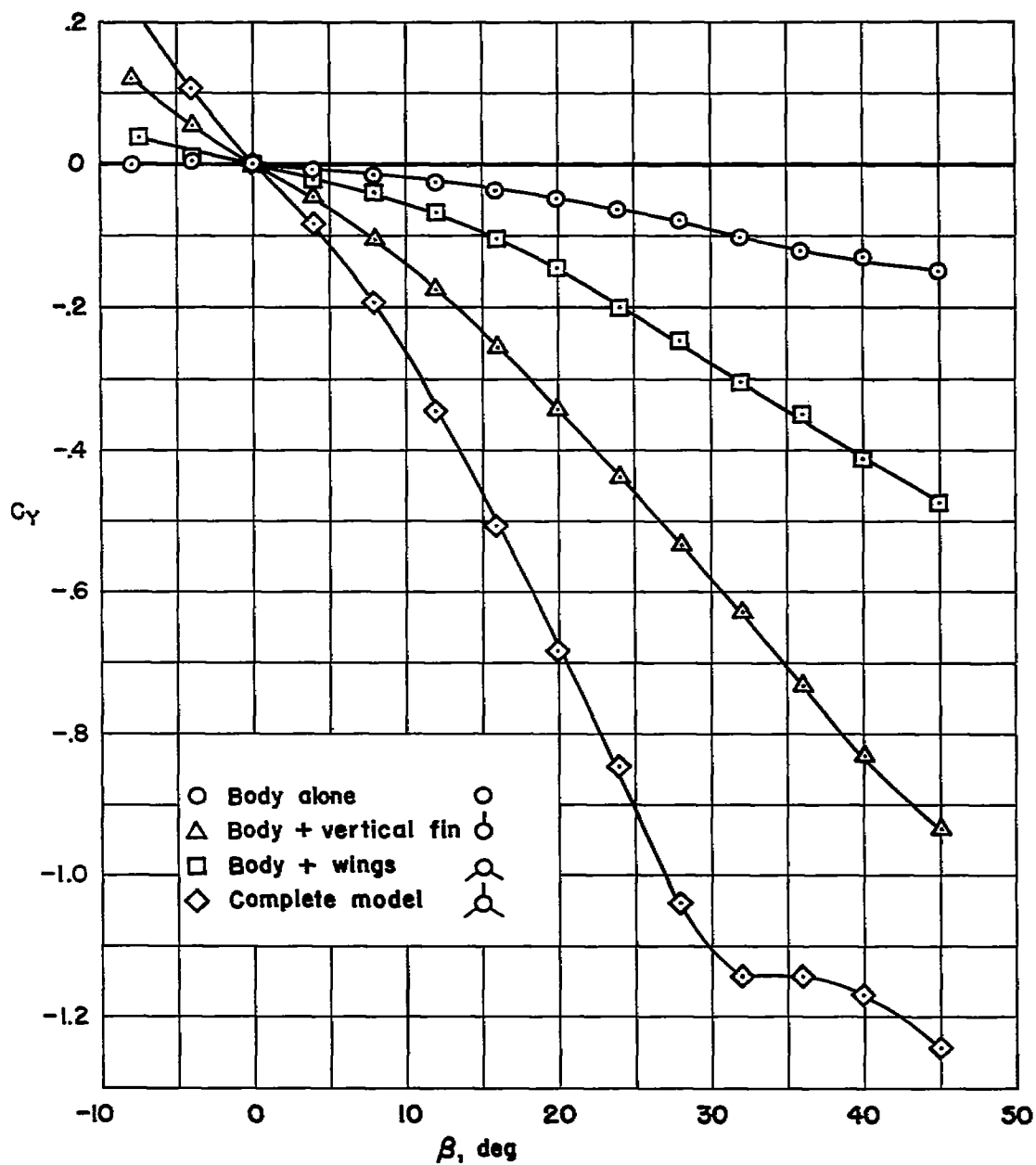
Figure 4.- Continued.





(c)  $\Gamma = -30^\circ$ .

Figure 4.- Continued.



(c) Concluded.

Figure 4.- Concluded.

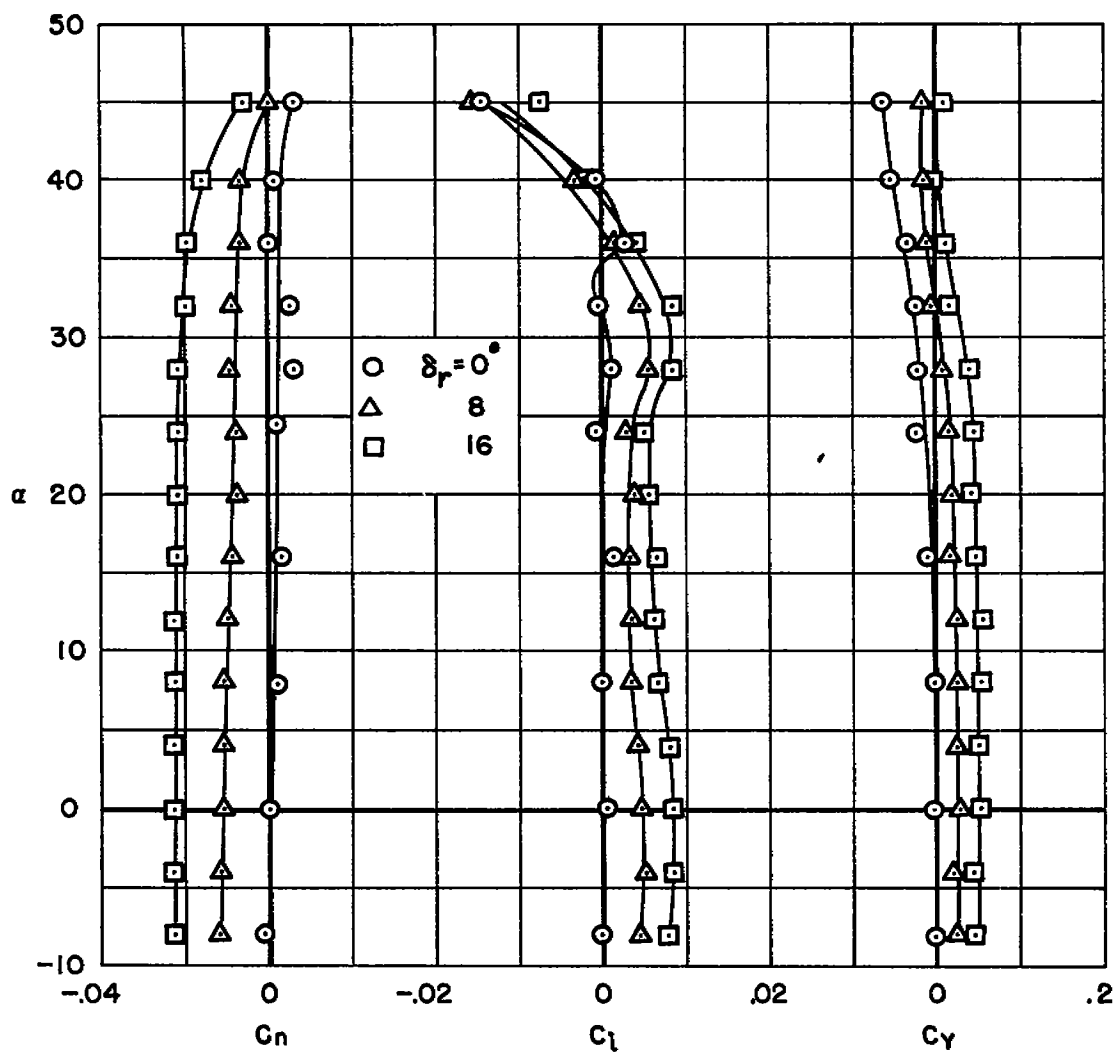
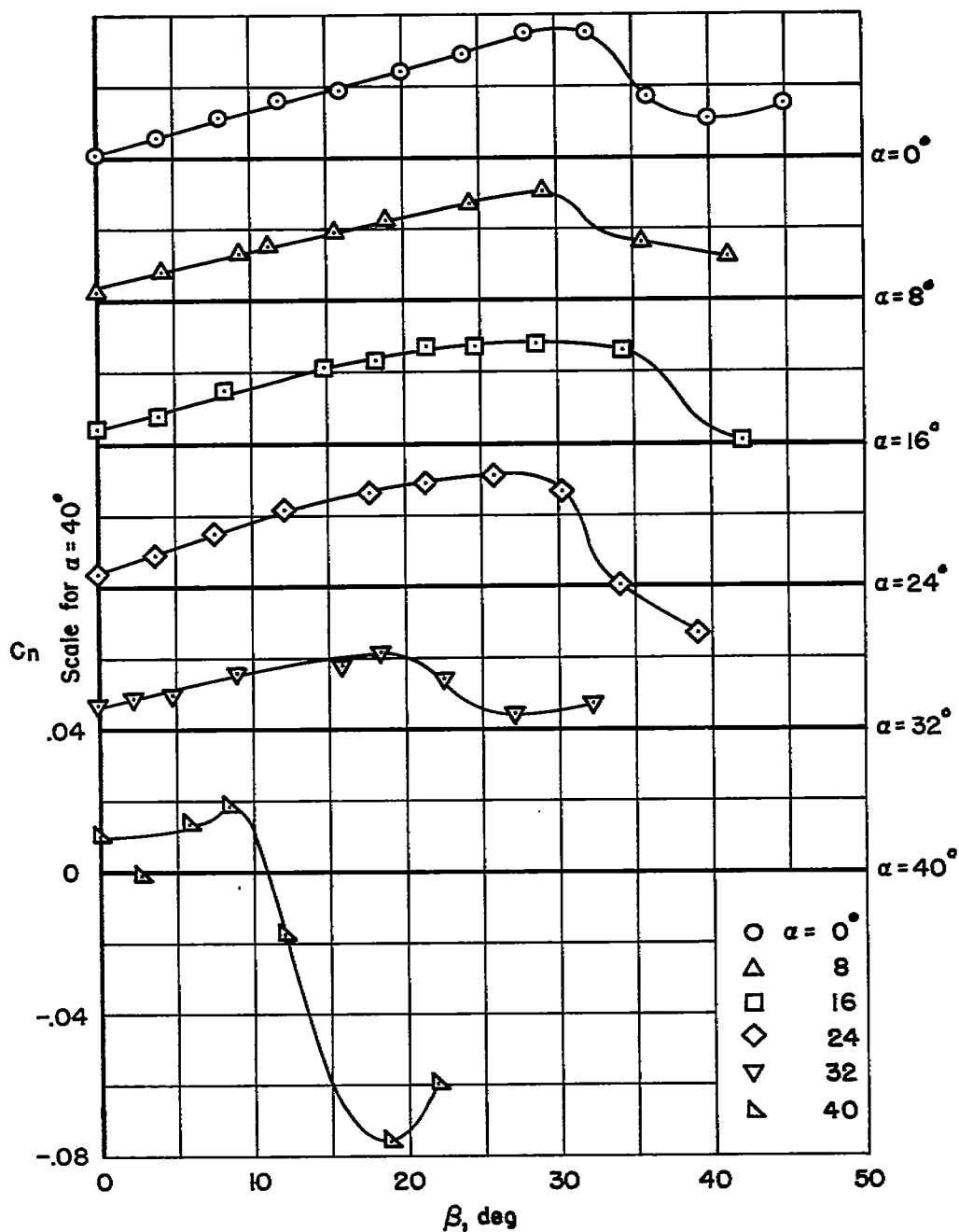
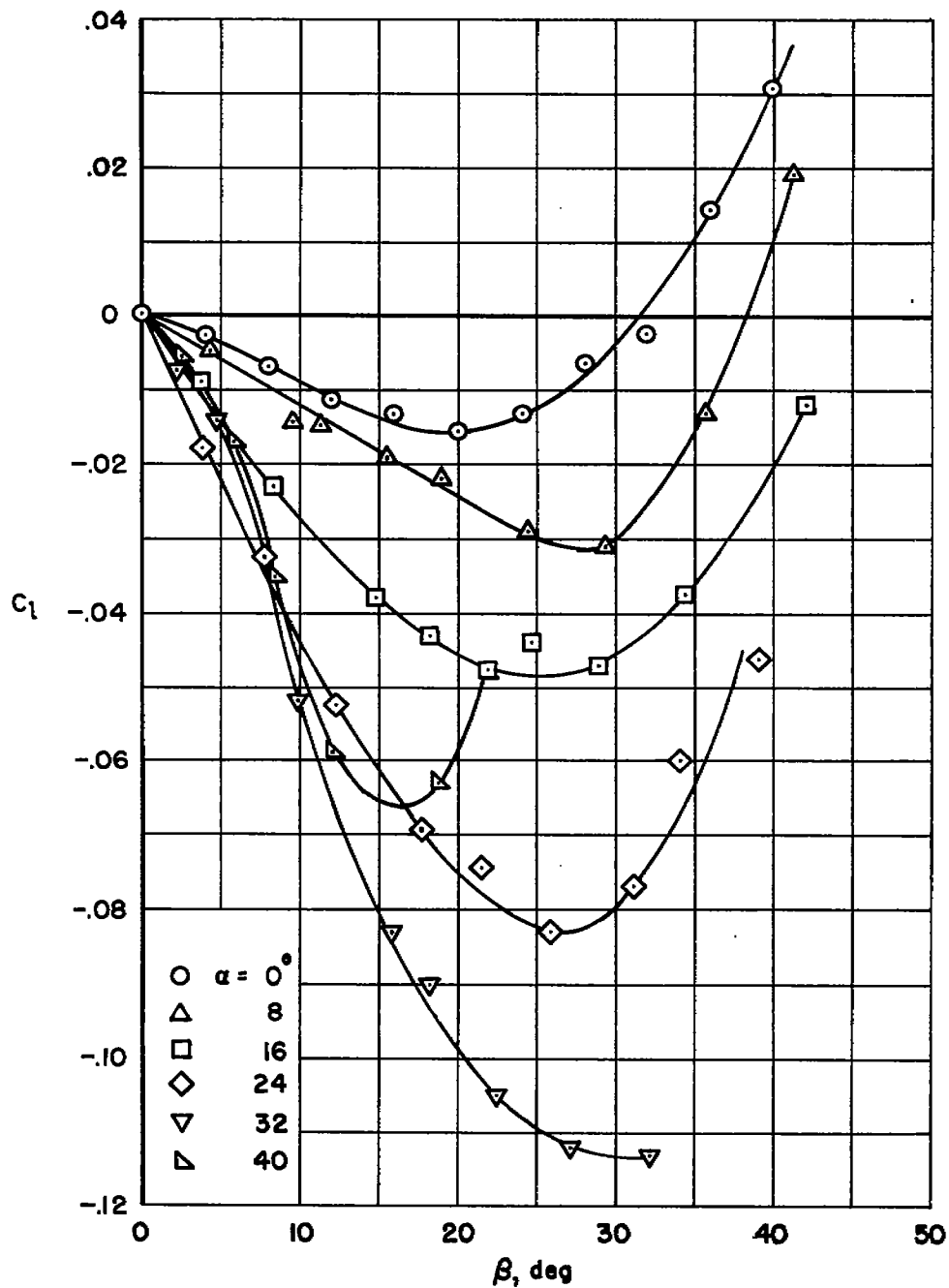


Figure 5.- The effect of angle of attack on the rudder effectiveness at zero sideslip;  $\Gamma = -30^\circ$ , large vertical fin.



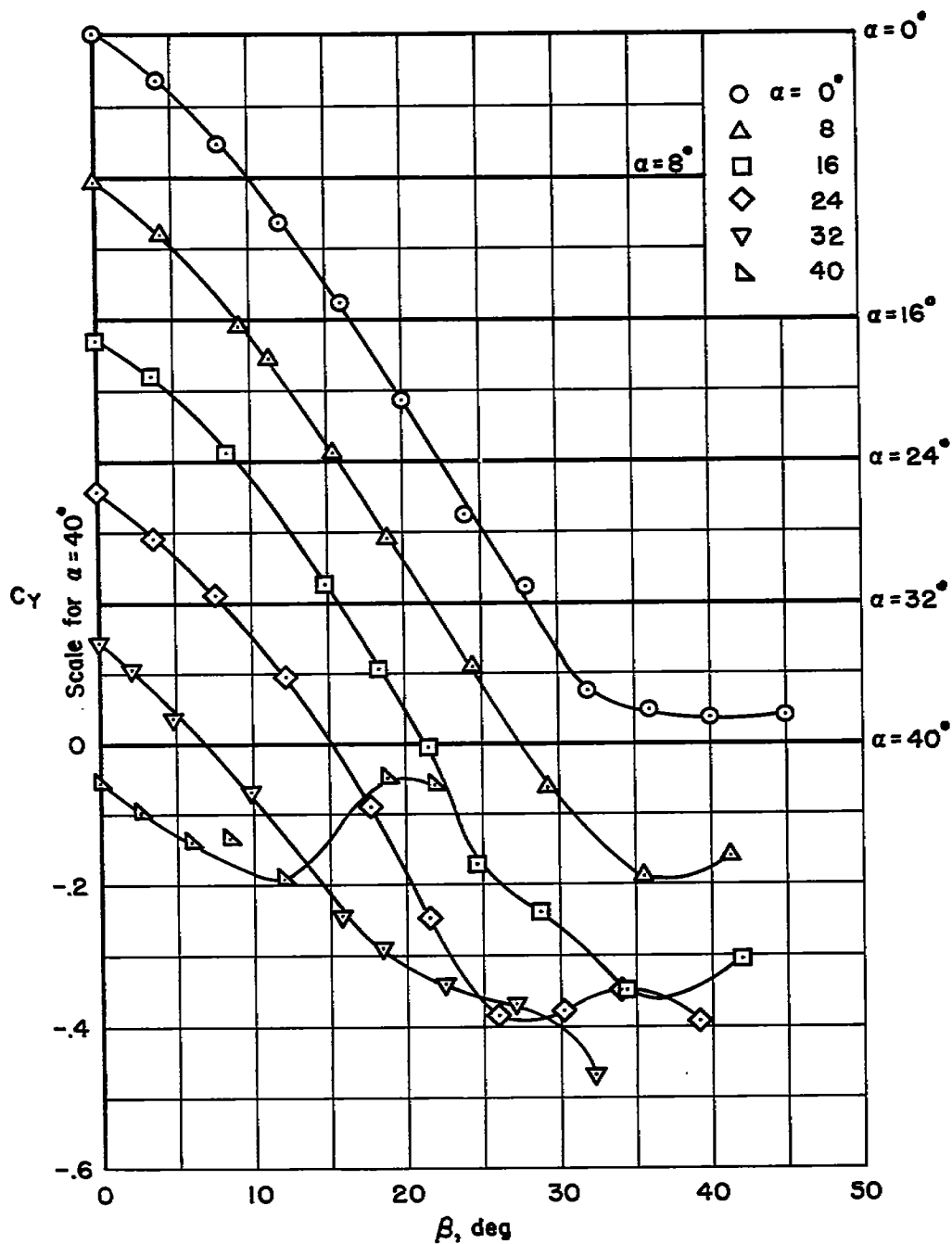
(a) Yawing-moment coefficient versus sideslip angle.

Figure 6.- Force and moment coefficients in sideslip for several angles of attack;  $\Gamma = -15^\circ$ , large vertical fin.



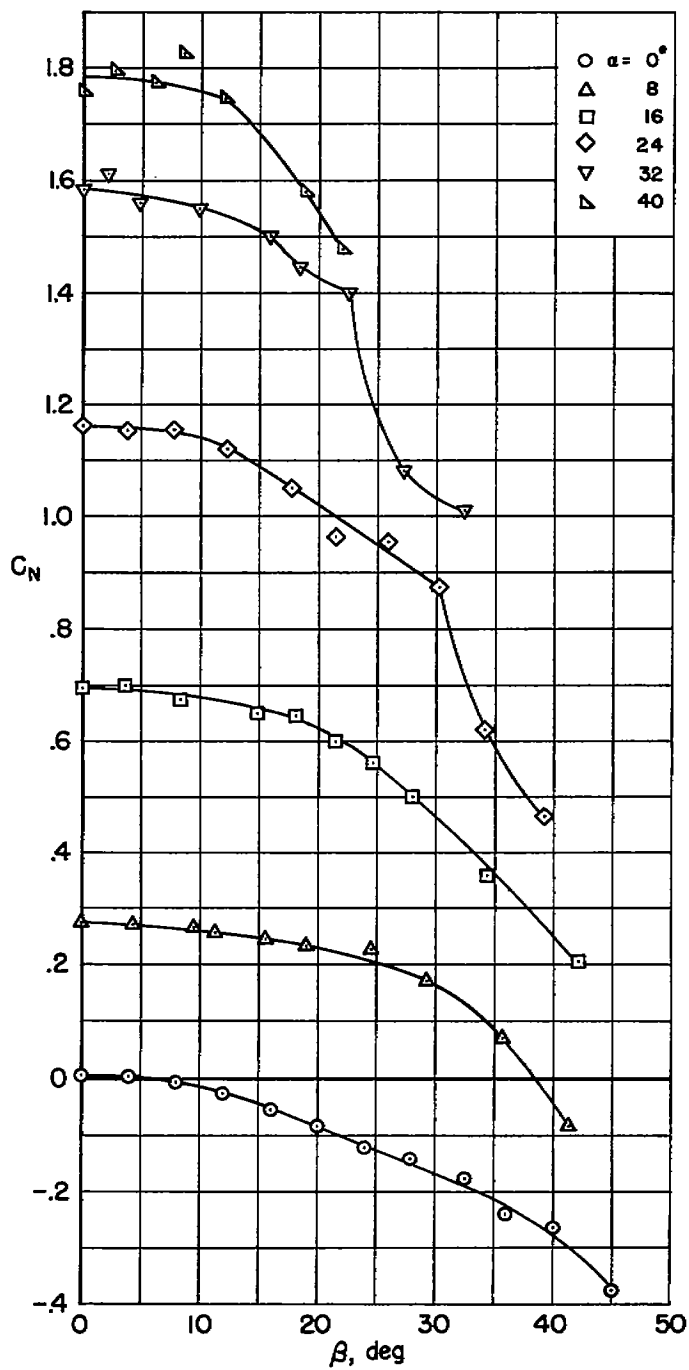
(b) Rolling-moment coefficient versus sideslip angle.

Figure 6.- Continued.



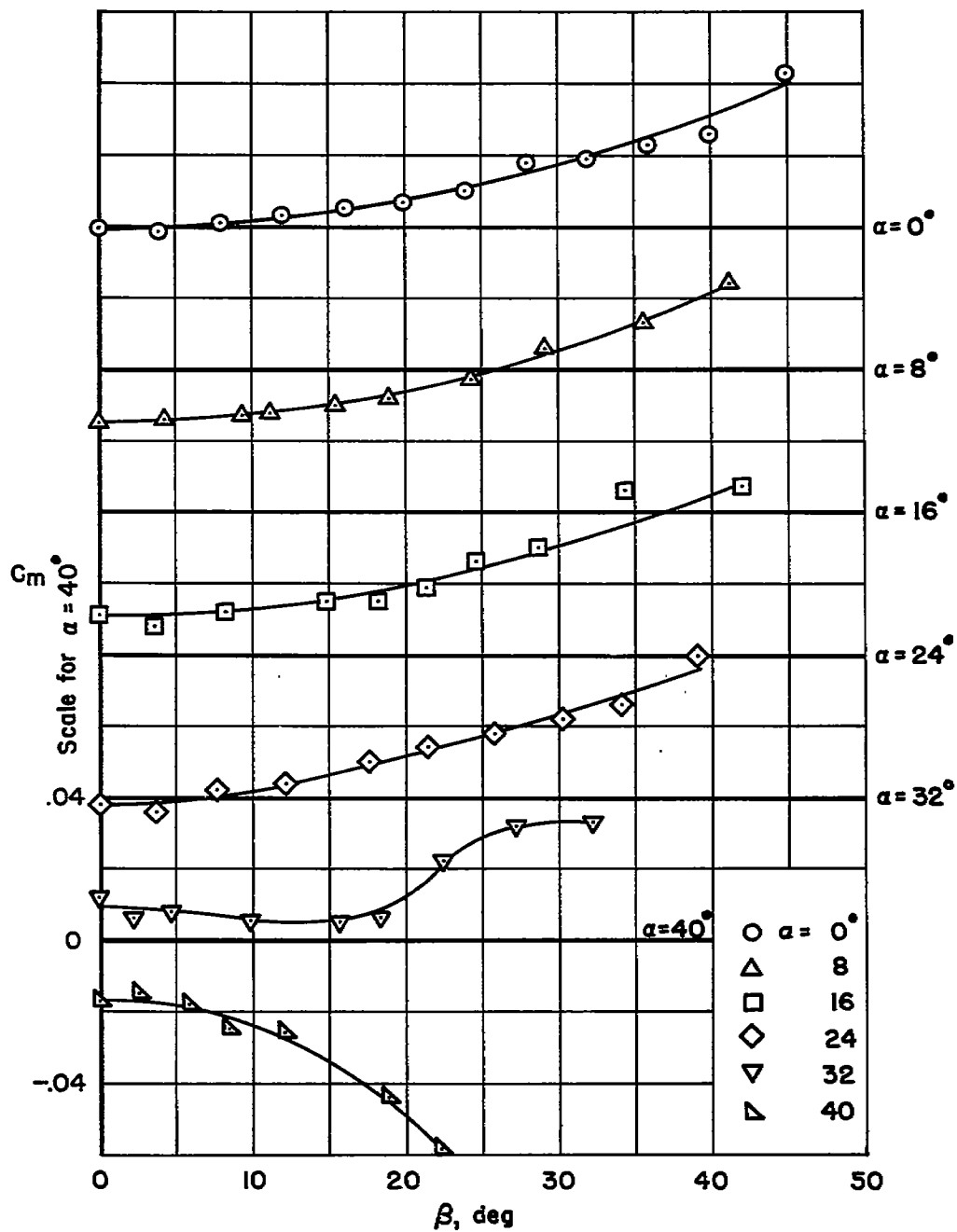
(c) Side-force coefficient versus sideslip angle.

Figure 6.- Continued.



(d) Normal-force coefficient versus sideslip angle.

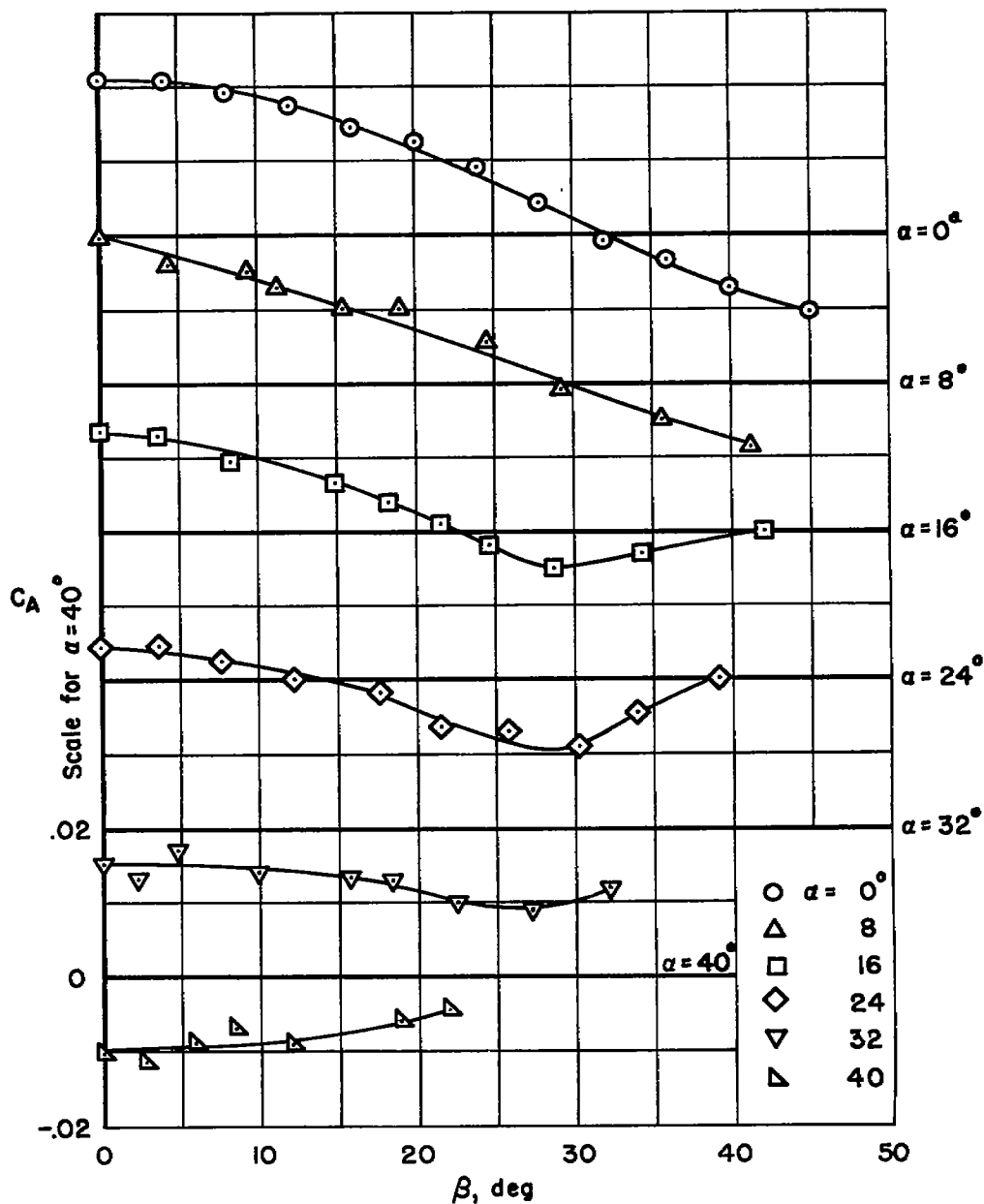
Figure 6.- Continued.



(e) Pitching-moment coefficient versus sideslip angle.

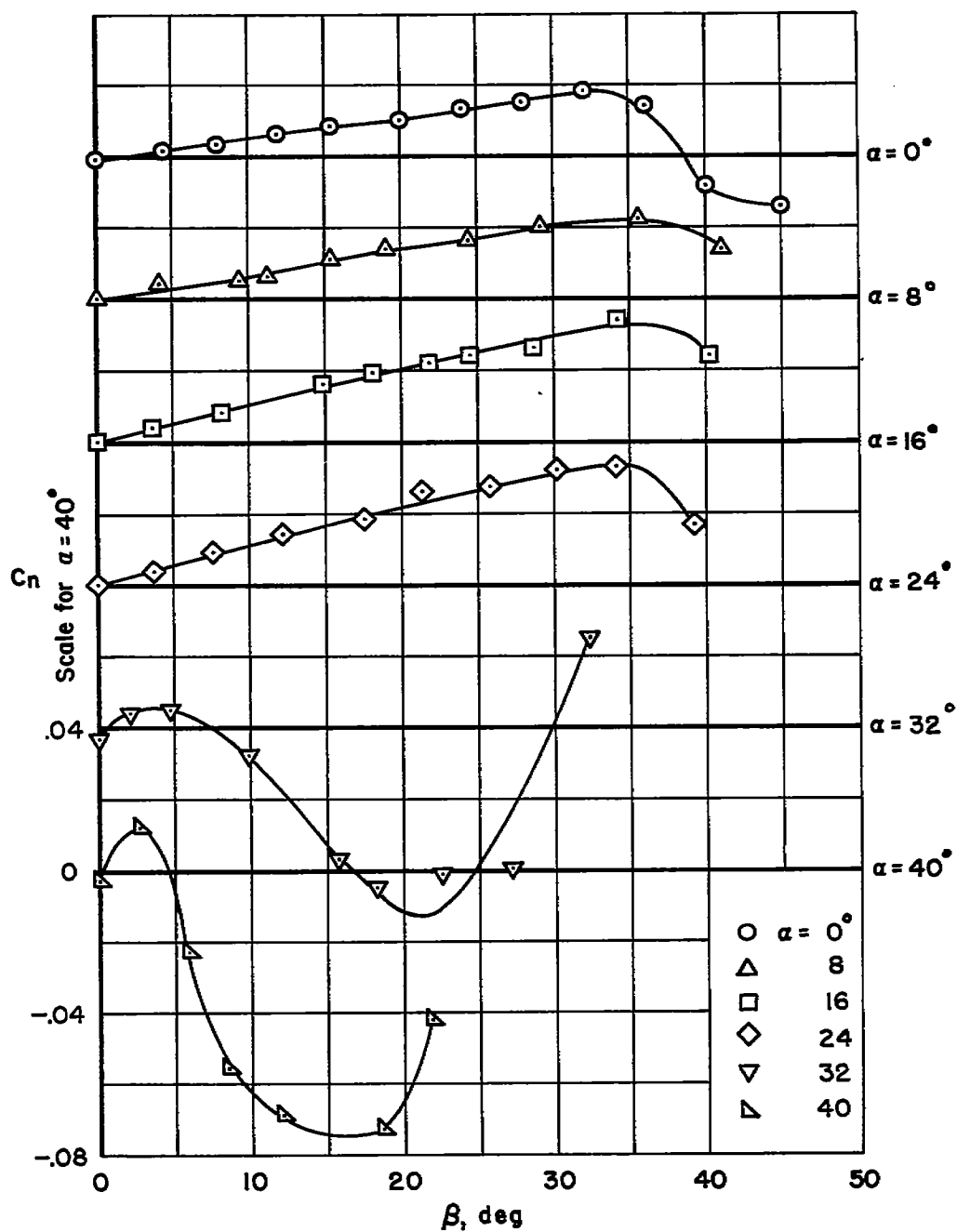
Figure 6.- Continued.





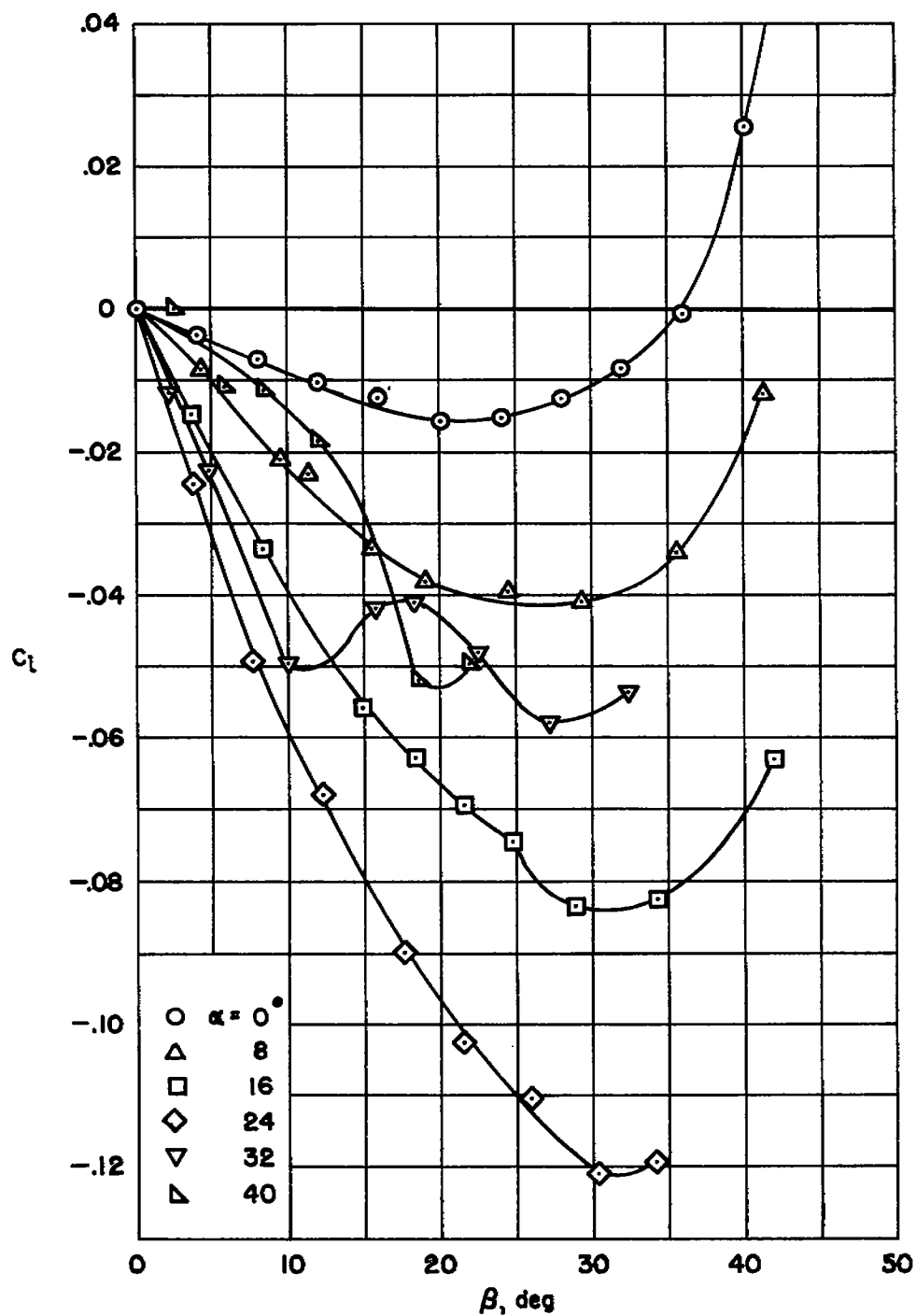
(f) Axial-force coefficient versus sideslip angle.

Figure 6.- Concluded.



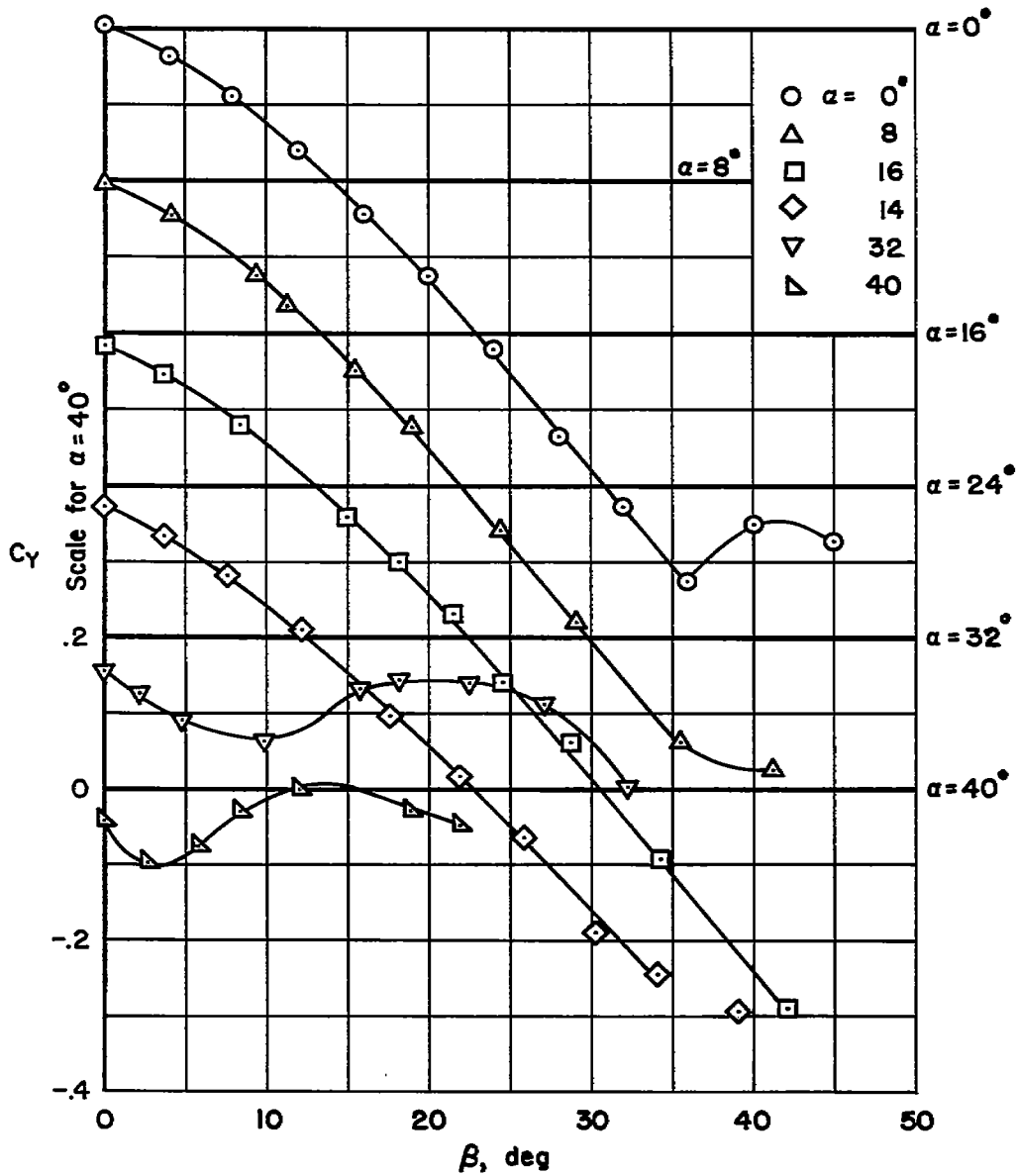
(a) Yawing-moment coefficient versus sideslip angle.

Figure 7.- Force and moment coefficients in sideslip for several angles of attack;  $\Gamma = 0^\circ$ , small vertical fin.



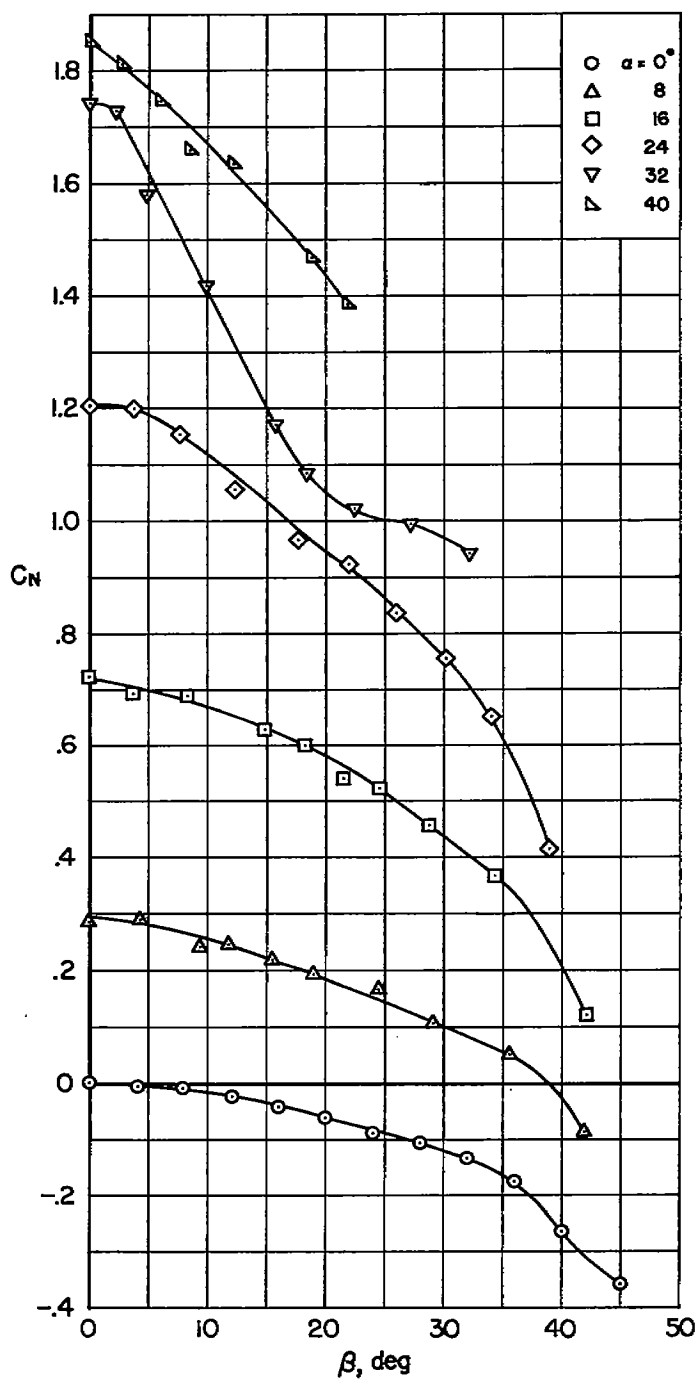
(b) Rolling-moment coefficient versus sideslip angle.

Figure 7.- Continued.



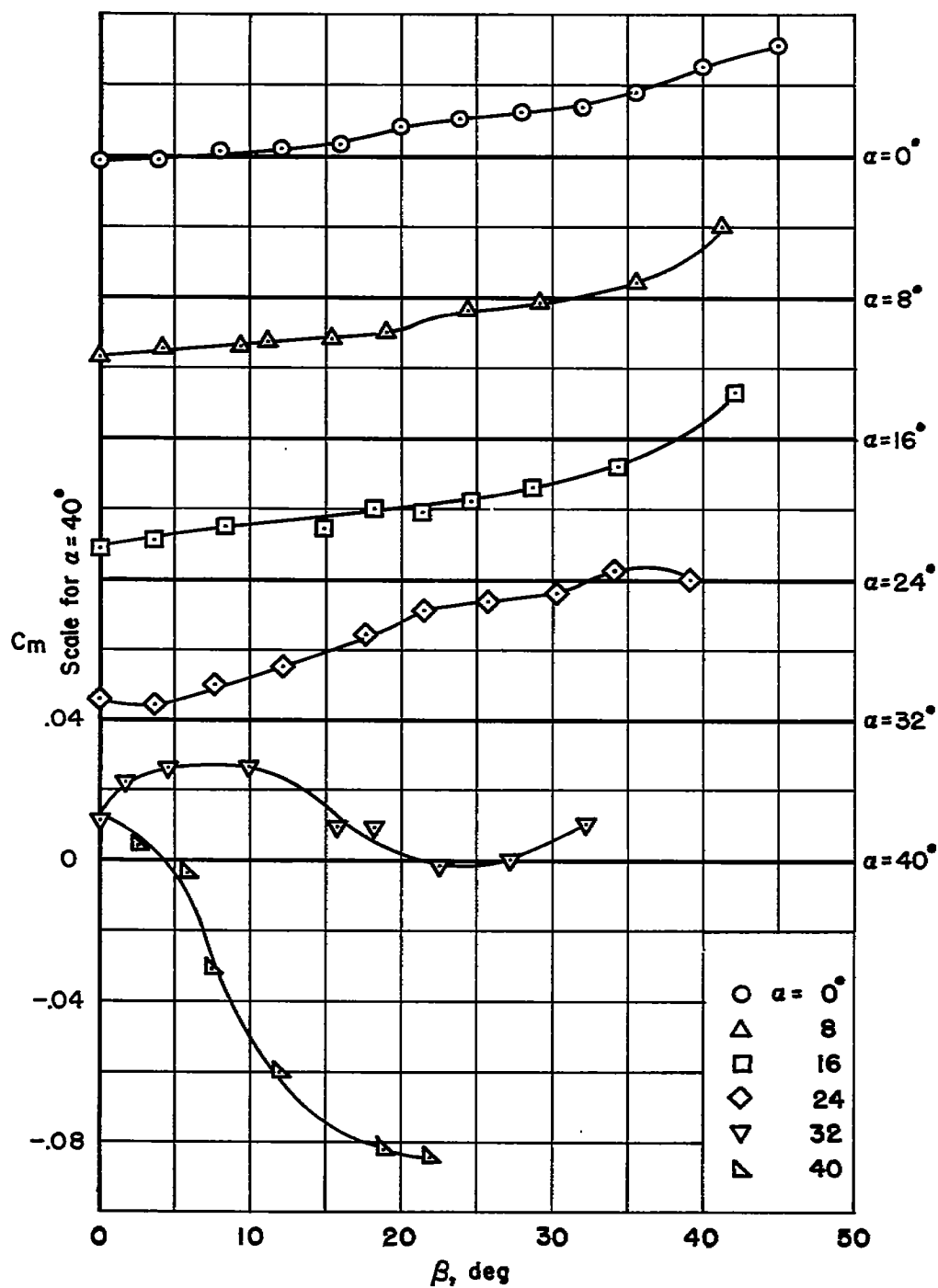
(c) Side-force coefficient versus sideslip angle.

Figure 7.- Continued.



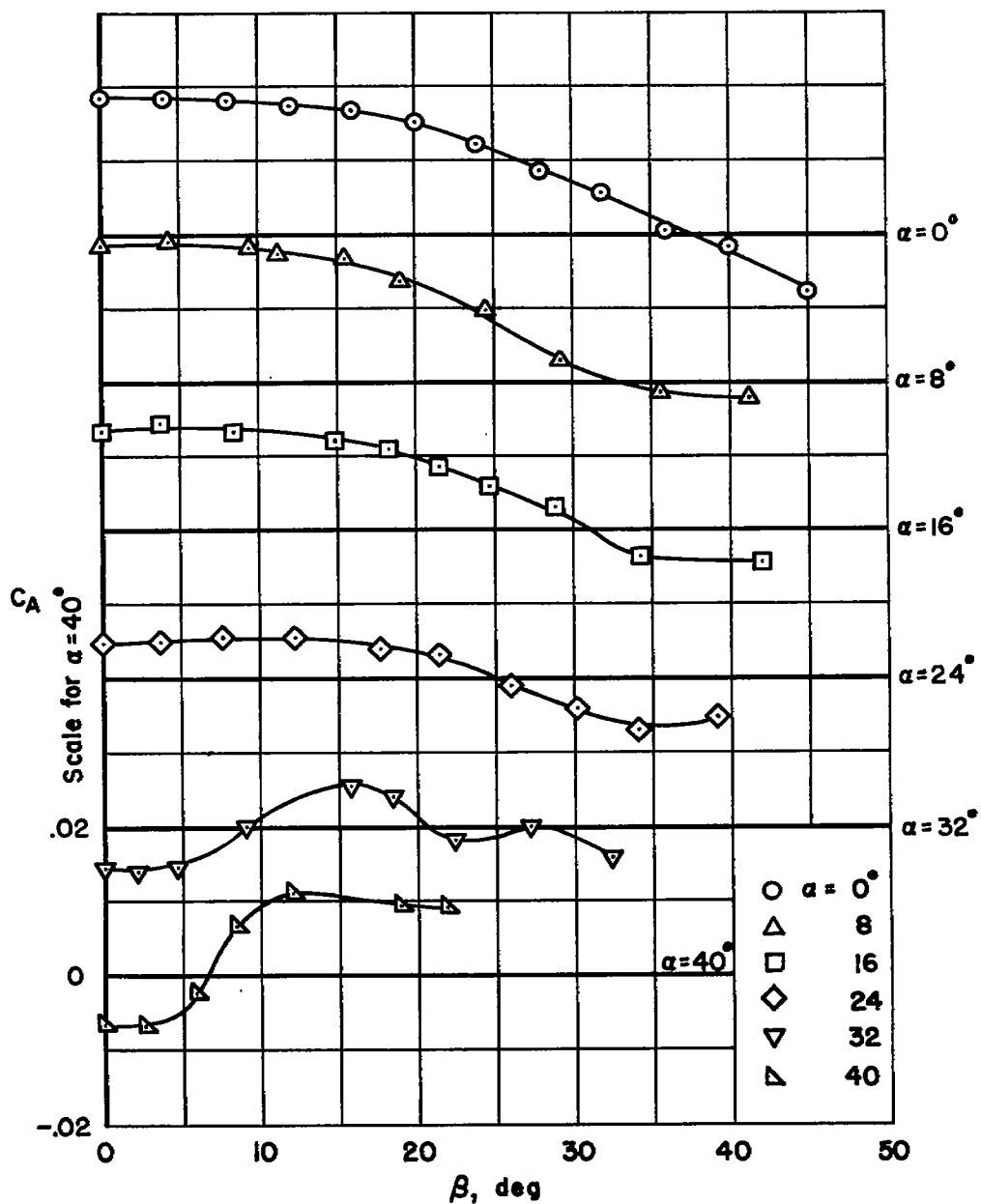
(d) Normal-force coefficient versus sideslip angle.

Figure 7.- Continued.



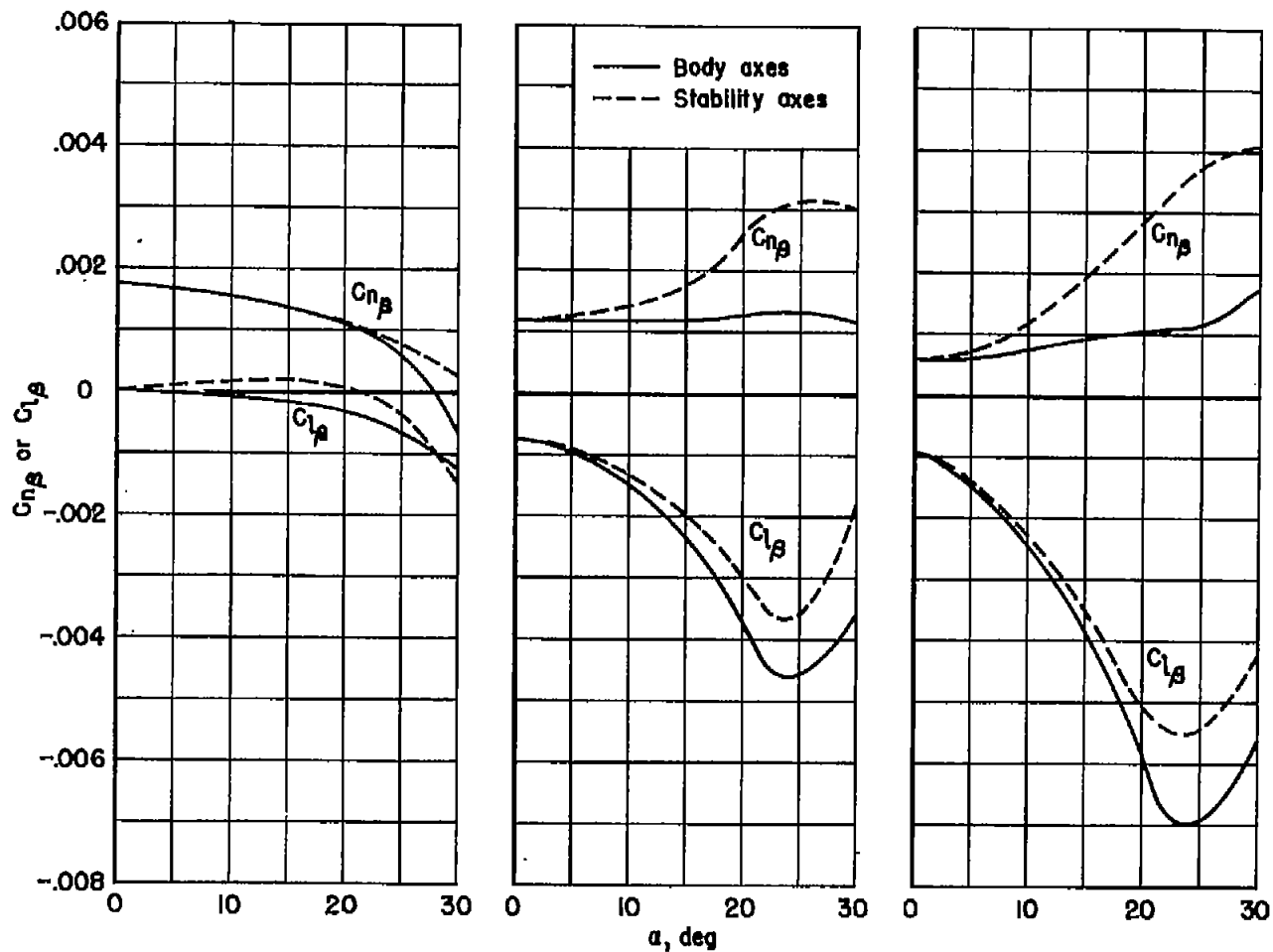
(e) Pitching-moment coefficient versus sideslip angle.

Figure 7.- Continued.



(f) Axial-force coefficient versus sideslip angle.

Figure 7.- Concluded.



(a)  $\Gamma = -30^\circ$ ; large vertical fin.

(b)  $\Gamma = -15^\circ$ ; large vertical fin.

(c)  $\Gamma = 0^\circ$ ; small vertical fin.

Figure 8.- Variation of  $C_{n\beta}$  and  $C_{l\beta}$  with angle of attack.





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